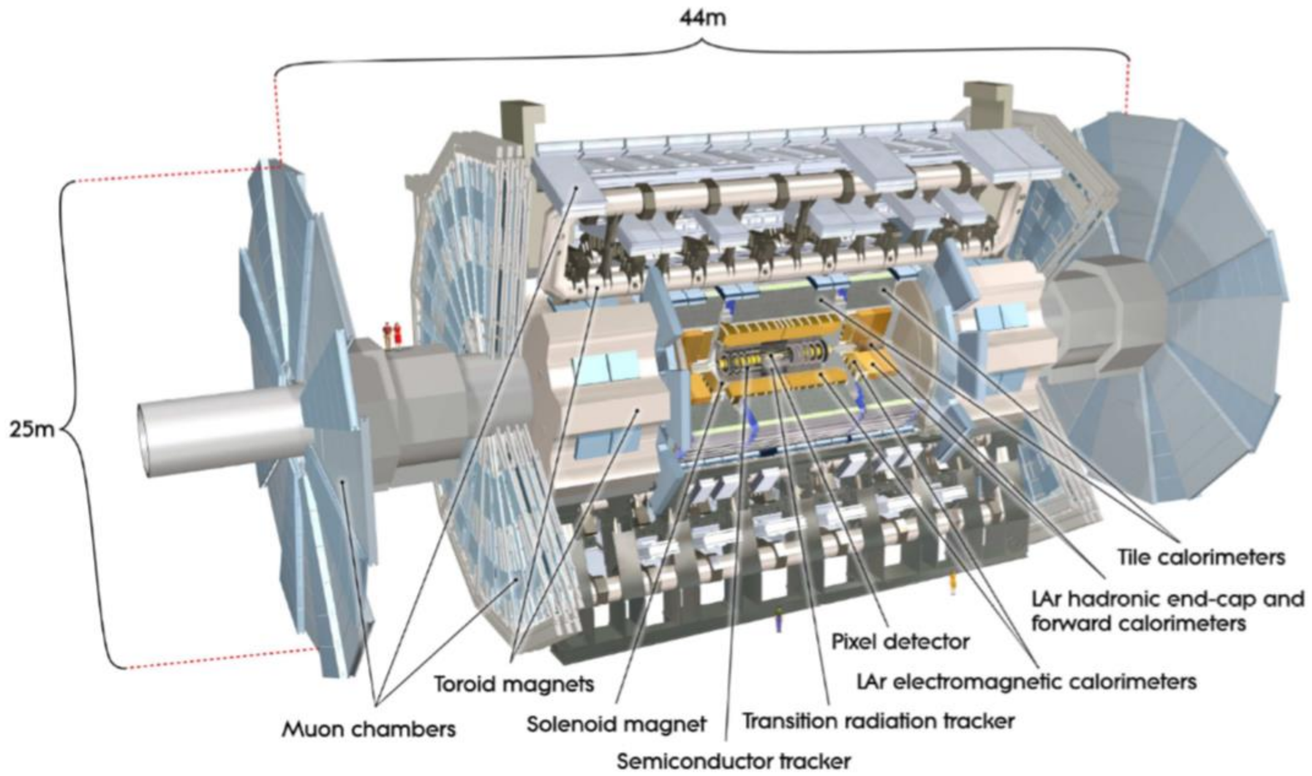
# Test of small-diameter monitored drift tube (sMDT) chambers for the ATLAS Muon-Spectrometer

# ATLAS Experiment



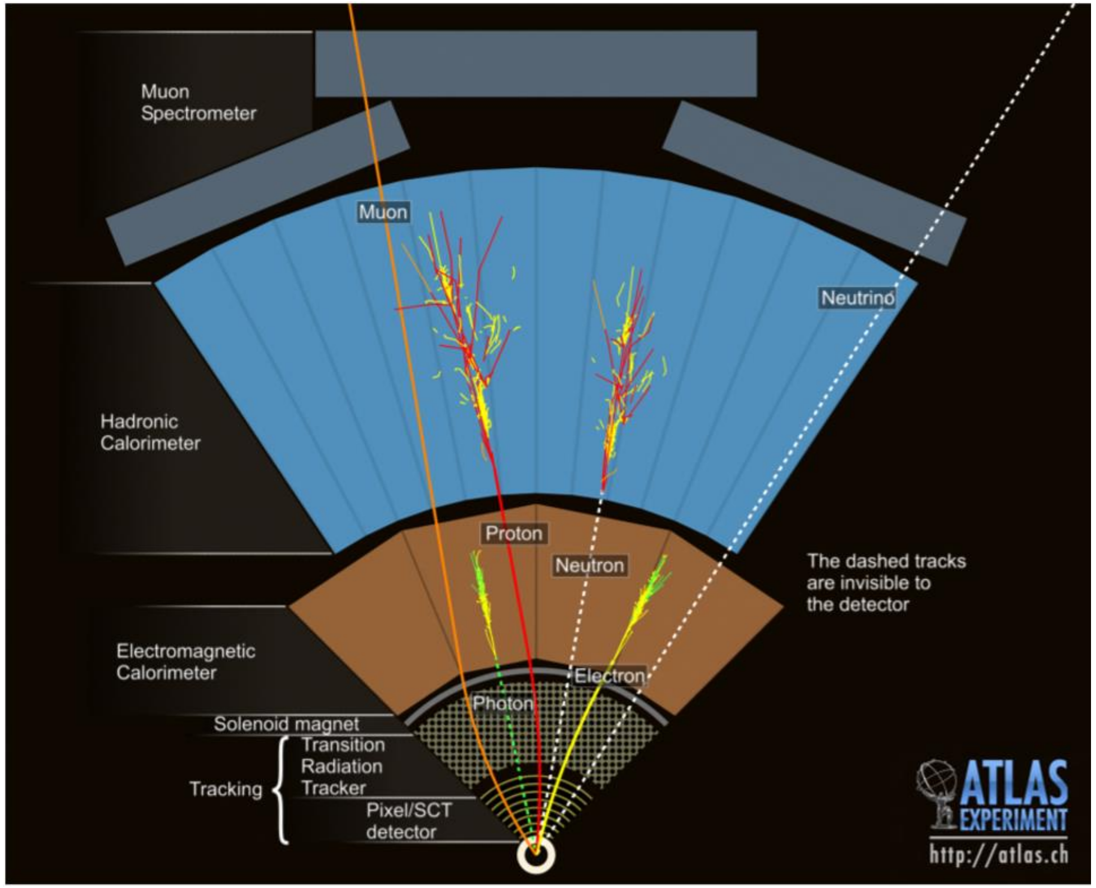

- Largest and most complex scientific instrument ever built
- LHC collides Protons with an energy of 13 TeV collisions
- ATLAS is a general purpose detector at one of the four collision points

# ATLAS motivation

- Study electroweak symmetry breaking: measurement of Higgs Boson couplings
- Search for physics beyond standard model
- precision measurements of Standard model processes and parameters
- Muons are key final states for lots of processes

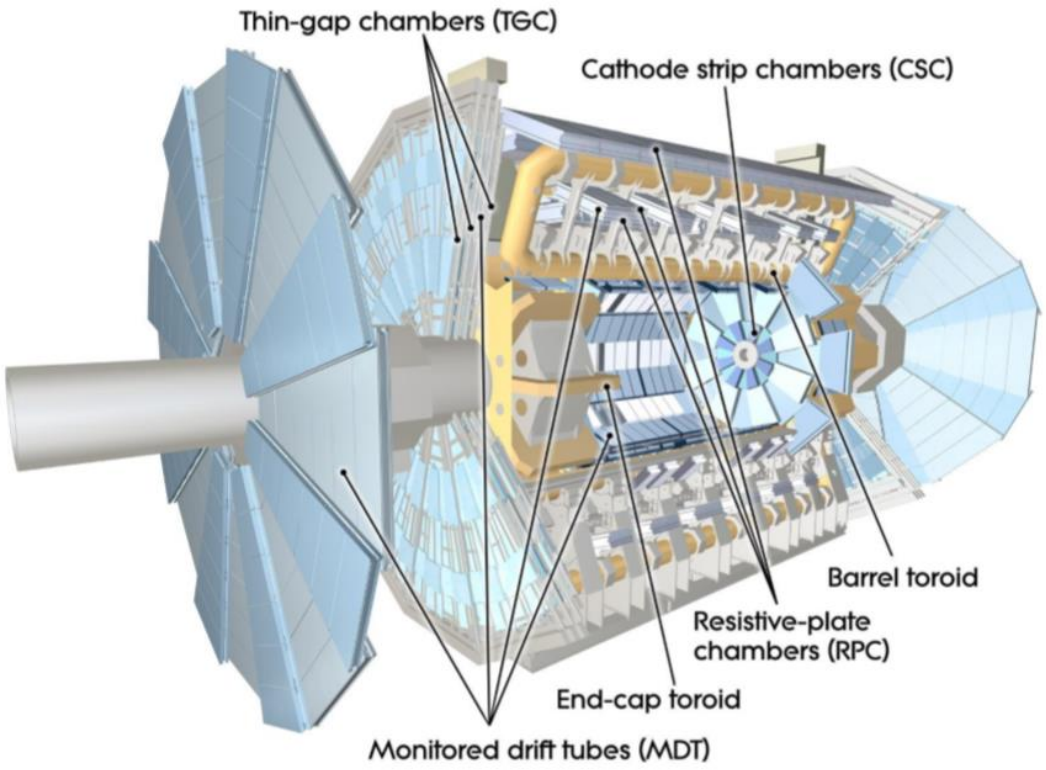
$\Rightarrow$ precise Muon spectrometer needed

# Detection of particles



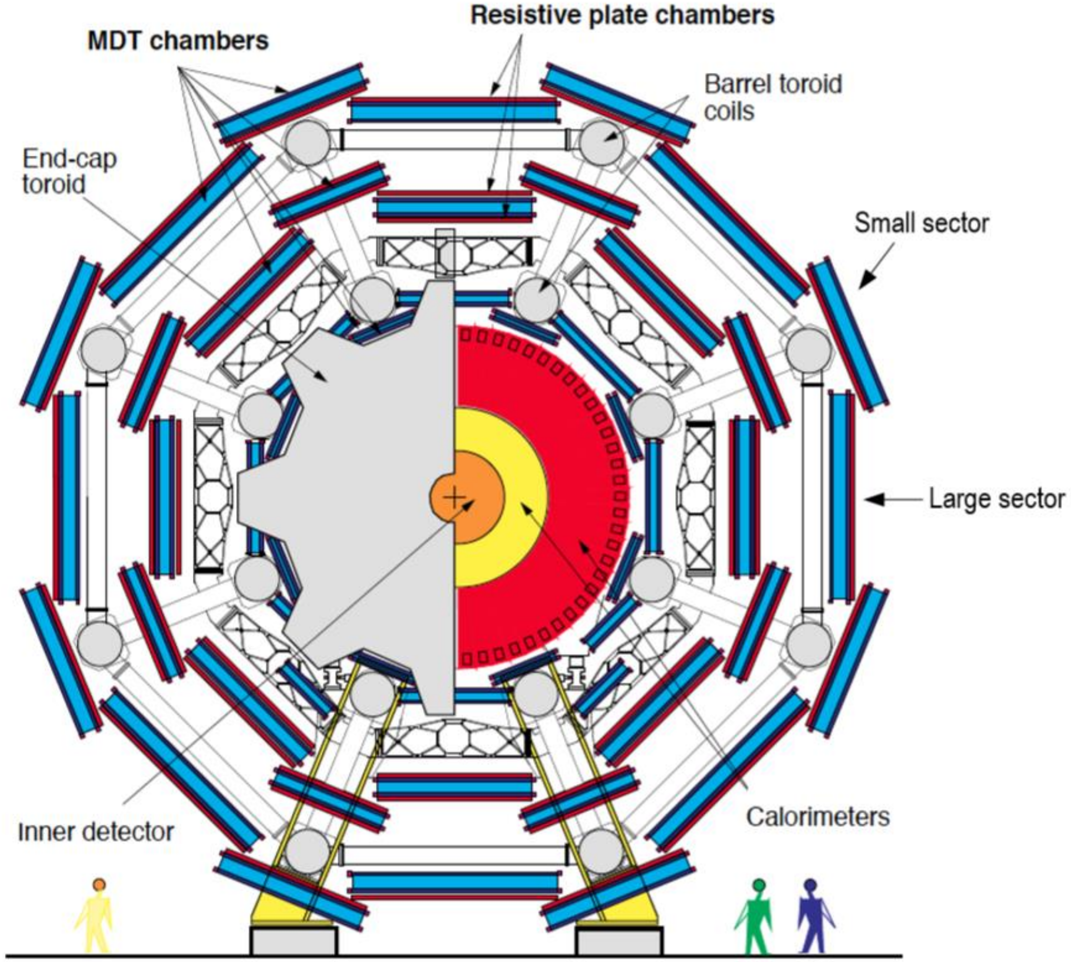

- Inner Detector: charge and momenta of charged particles
- Calorimeters: energy of photons, electrons and hadrons
- Calorimeter stops electrons, photons and hadrons
- Muon-Spectrometer: Largest part of the detector

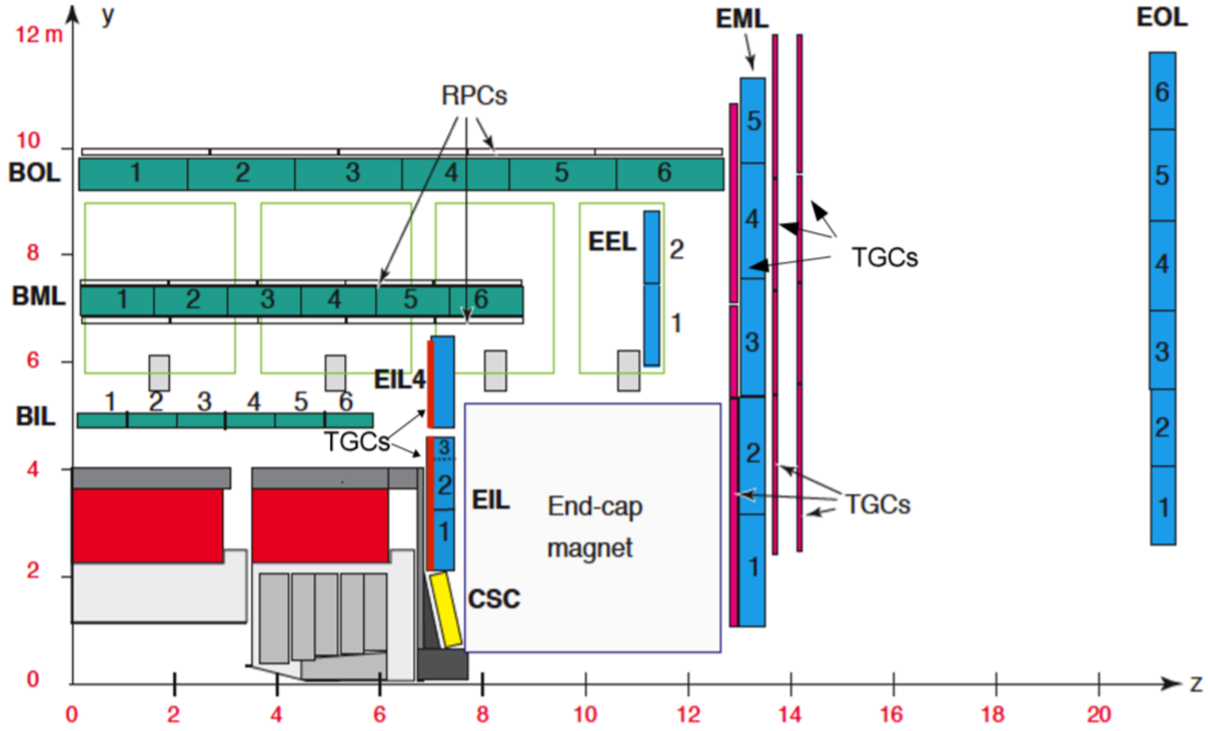
# Muon Spectrometer




- Detect and measure Muon momenta
- Bending their trajectories with large superconducting air-core toroid magnets
- Gaseous detectors for precision spatial measurements
- Fast trigger chambers for timing and triggering

# Muon Spectrometer



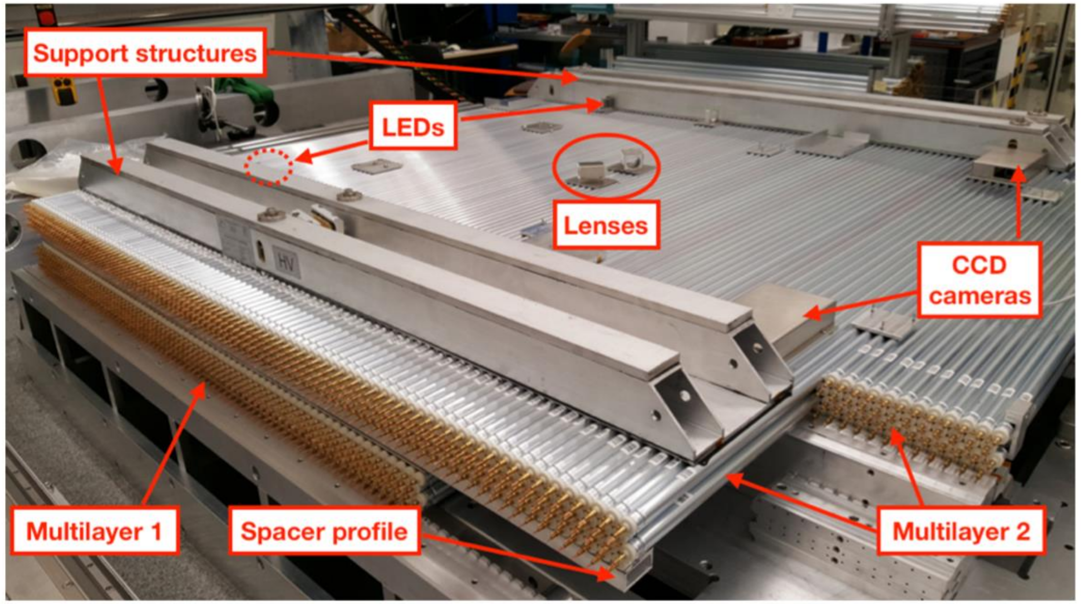



# RPC and MDT chambers

MDTs: tracking the trajectories of the muons

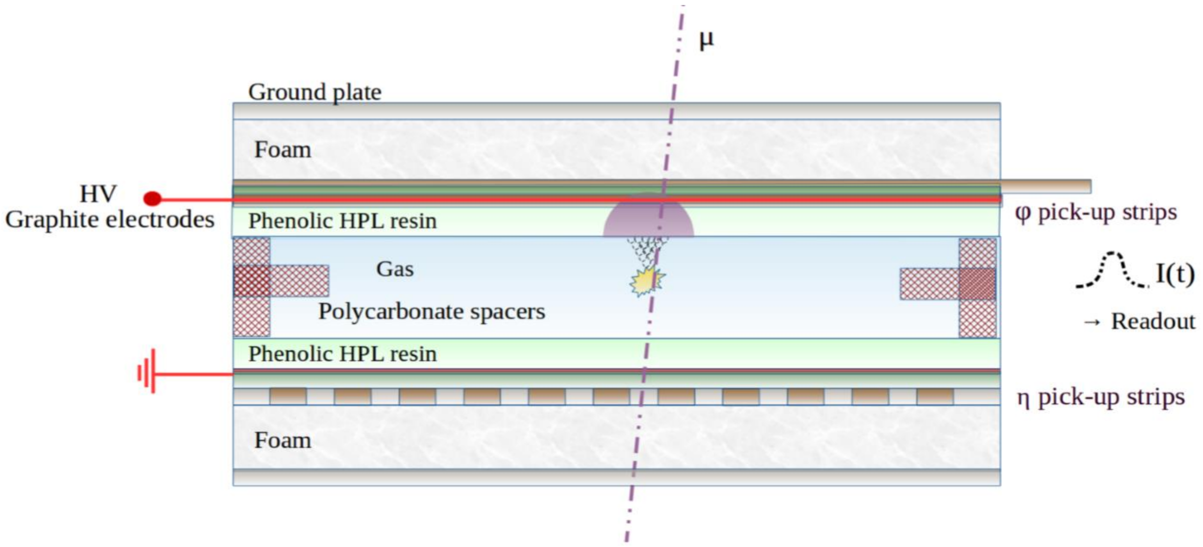
composed of drift tubes filled with gas

RPCs: triggering chambers for fast triggering of the muons



# RPCs

- Large planar capacitor filled with gas
- Uniform electric field
- Electron avalanche immediately after ionization
- Reconstruction of trajectories in the endcap region



# LHC upgrades

HL-LHC upgrade: Phase 1: upgrade of injectors

Phase 2: new focussing magnets and crab cavities

Goal: increase integrated luminosity by a factor of 10 for further scientific researches concerning the standard model

ATLAS detector must be upgraded for larger amounts of data

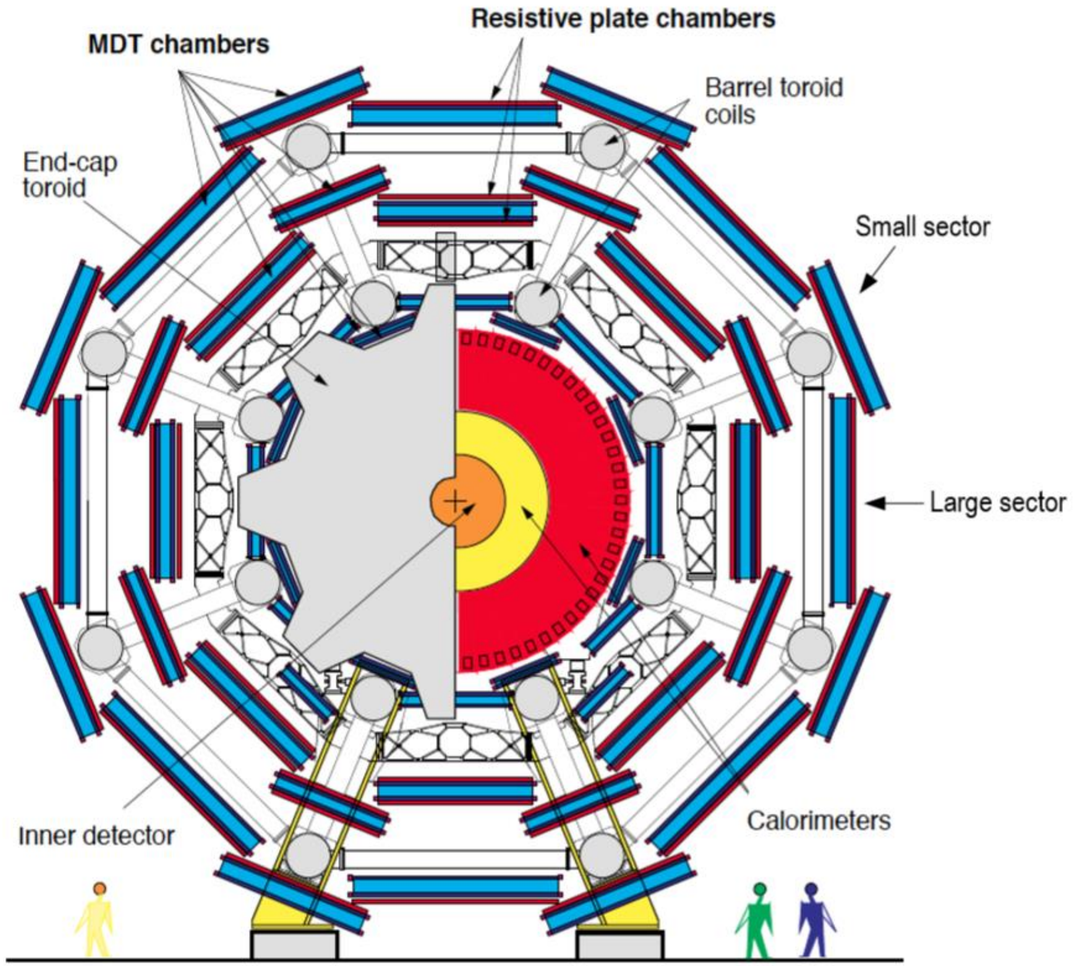
# Muon spectrometer upgrades

- BIS 78 pilot project
- BIS sMDT upgrade
- Replacement of large parts of frontend- ,trigger- and readout electronics
- Completely redesigned trigger scheme for RPCs and TGCs
- Power system replacements
- MDT-upgrade of frontend-, trigger- and readout electronics

# BIS sMDT upgrade project

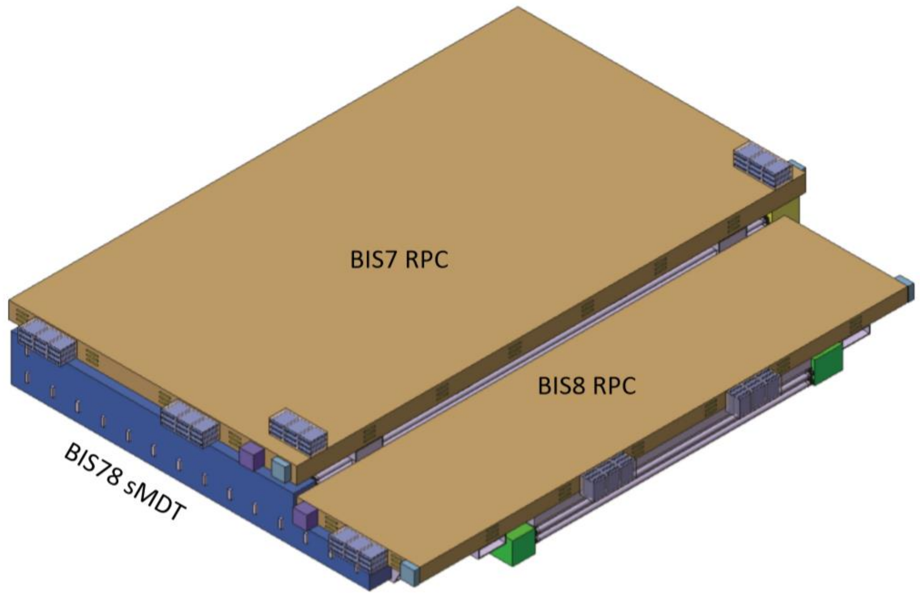
Problem: significant rate of fake muon triggers

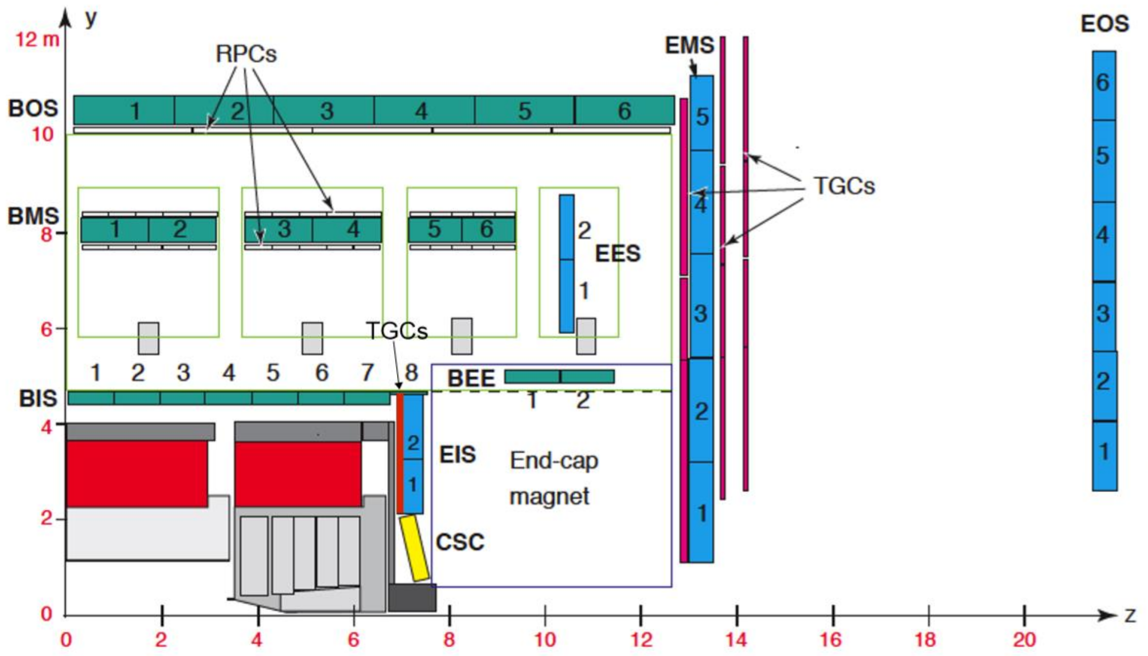
- For areas with poor acceptance: additional thin-gap RPCs
- not enough space: sMDTs instead of MDTs in BI small sectors



# BIS 78 pilot project

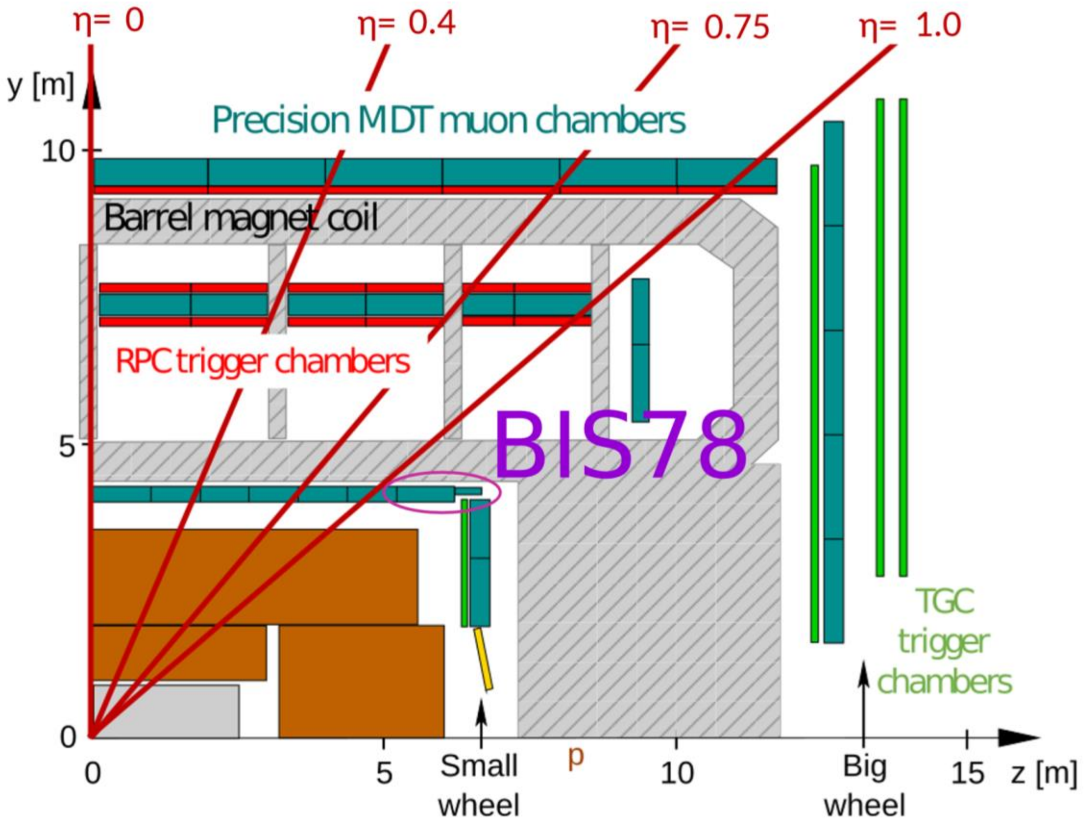
- Installed in barrel-endcap-transition region with poor acceptance
- Single two mulitlayer sMDT chamber and RPC triplets
- Performance is studied for further upgrades (BIS sMDT)



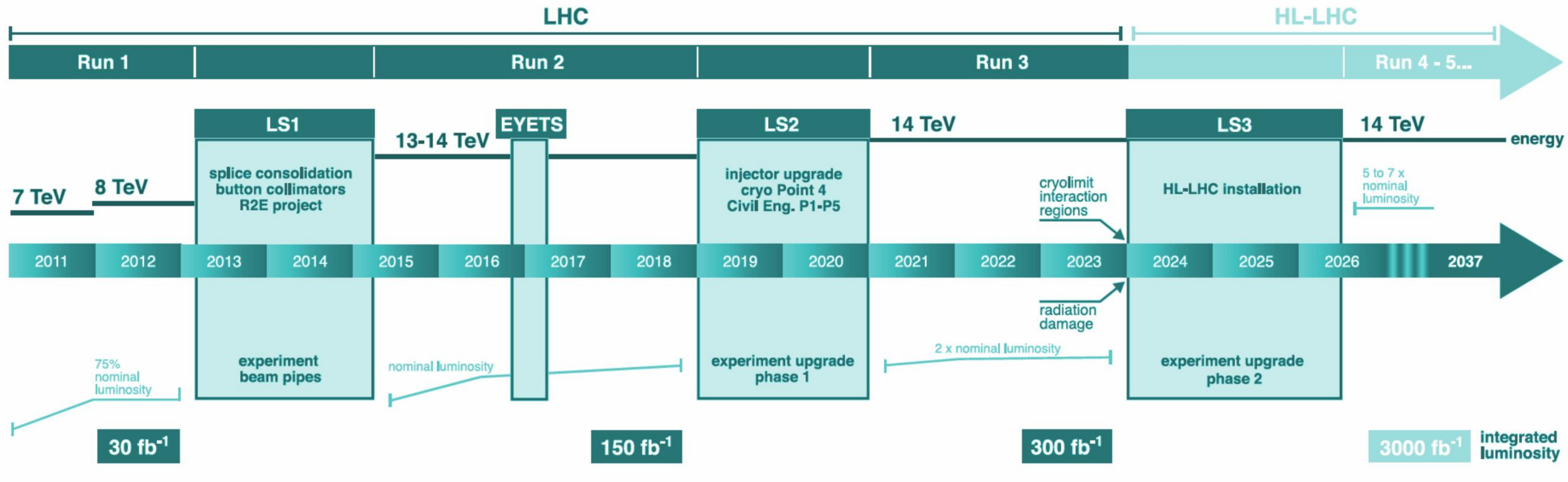



# BIS 1-6 upgrade

- All BIS chambers will be replaced by sMDTs & RPCs
- Simpler geometry
- In-Plane alignment system between the mulitlayers
- Better positioning of platforms
- Constructed during run 3



# Timeline of the upgrade

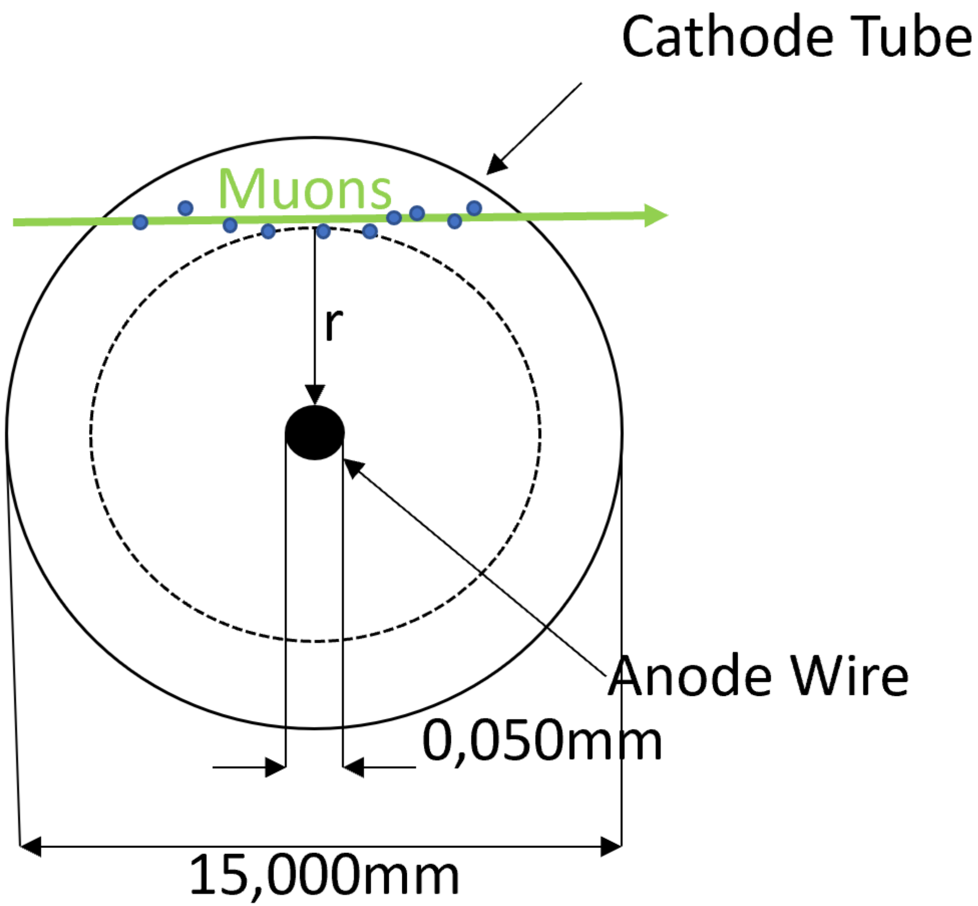



- 16 sMDT chambers + RPCs in LS2 (BIS78)
- 96 sMDT chambers + RPCs in LS3 (BIS 1-6)

# Differences between sMDT and MDT tubes

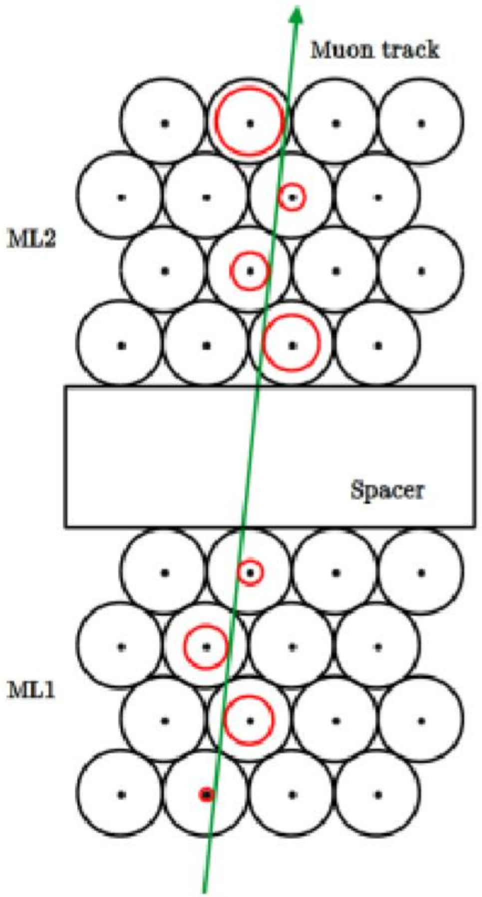
| **Parameter** | **MDT** | **sMDT** |
|---|---|---|
| Tube material | Aluminium | Aluminium |
| Outer tube diameter | 29.970 mm | 15.000 mm |
| Tube wall tickness | 0.4 mm | 0.4 mm |
| Wire material | gold-plated W/Re (97/3) | gold-plated W/Re (97/3) |
| Wire diameter | 50 $\mu m$ | 50 $\mu m$ |
| Gas mixture | Ar/$CO_2$ (93:7) | Ar/$CO_2$ (93:7) |
| Gas pressure | 3 bar (absolute) | 3 bar (absolute) |
| Gas gain | $2 \times 10^4$ | $2 \times 10^4$ |
| Wire potential | 3080 V | 2730 V |
| Maximum drift time | $\sim$ 700 ns | $\sim$ 190 ns |
| Average resolution per tube | 83 $\mu m$ | 106 $\mu m$ |
| Drift tube muon efficiency | 95% | 94% |

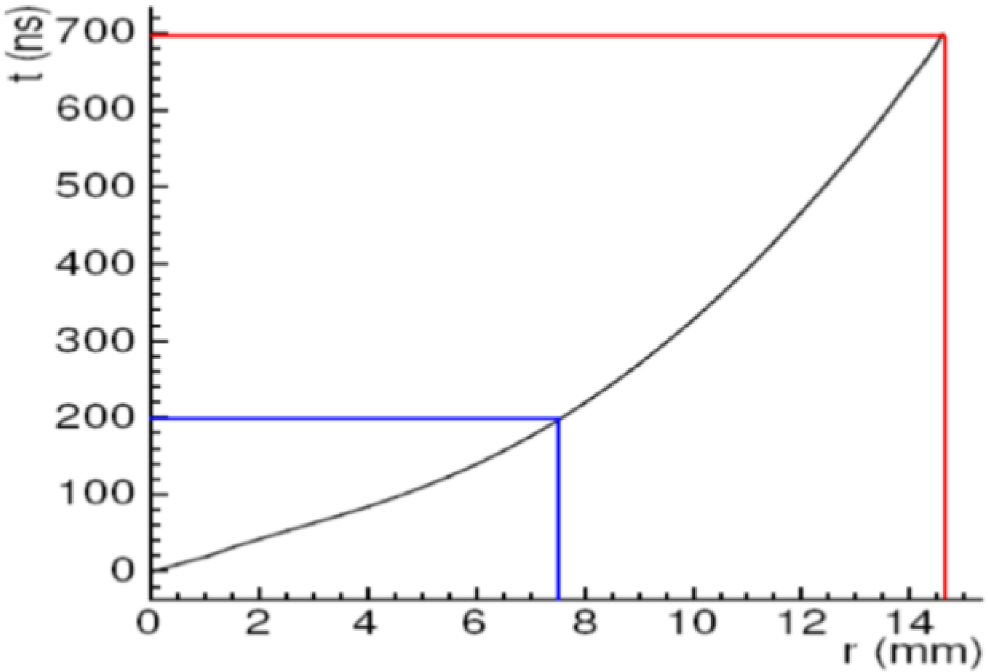
# Functioning principle of drift tubes




- Gas filled aluminium cylinders
- Grounded tube wall
- HV applied to wire
- Mouns ionize gas atoms
- Electrons drift towards wire
- Create an avalanche of electrons
- Positive ions drift towards tube wall

# Reconstruction of trajectory

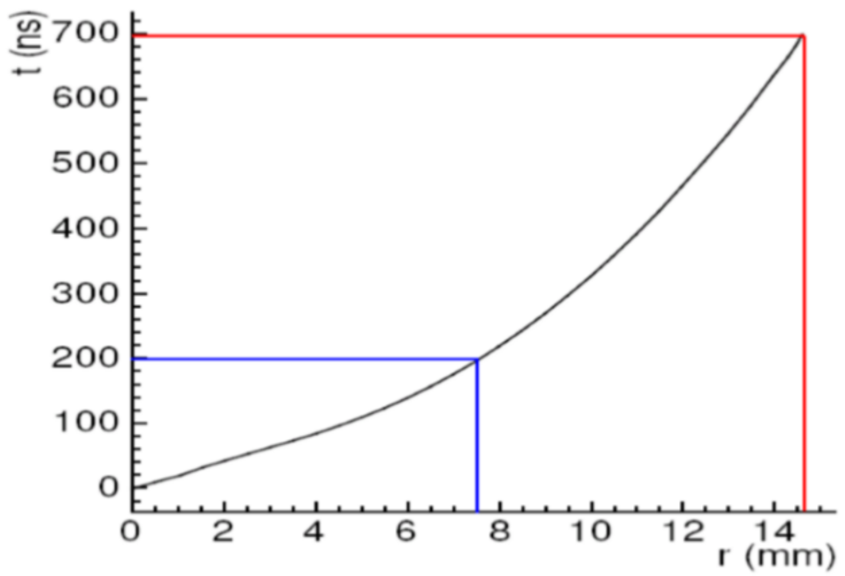


# Resolution on a momentum measurement

- Multiple scattering
- Intrinsic resolution of tracking chambers
- Uncertainity in the relative position of the muon chamber
- Magnet coils
- Interaction vertex
- Uncertainity in the magnetic field map
- Energy loss to the calorimeters

# Advantages of small-diameter drift tubes



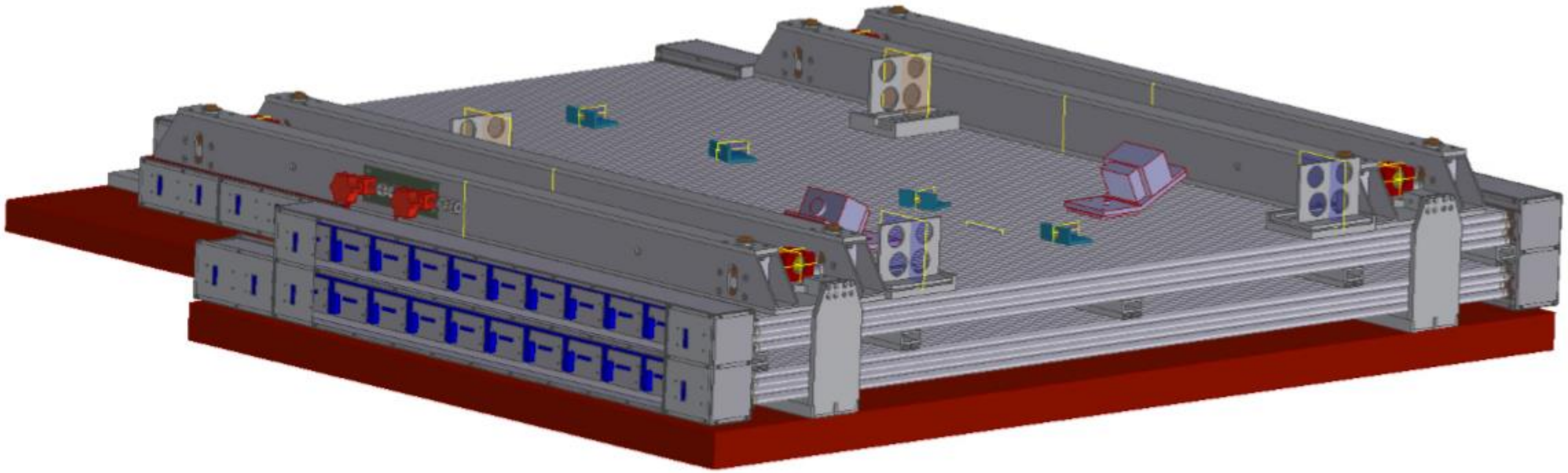

- Smaller maximum drift time
- Half size cross section exposed to radiation
- Prevents space-charge fluctuations
- Uncharged operational parameters
- Different wire potential
- 8 tube layers

# Drift tube design and fabrication

- Optimized for mass production
- High accuracy in wire positioning
- Ground connections in holes between tubes
- Gas connectors
- Certain wire tension

# Design of sMDT Chambers

- Several tube layers glued to a supporting frame
- Platforms, Lenses and LEDs for position measuring

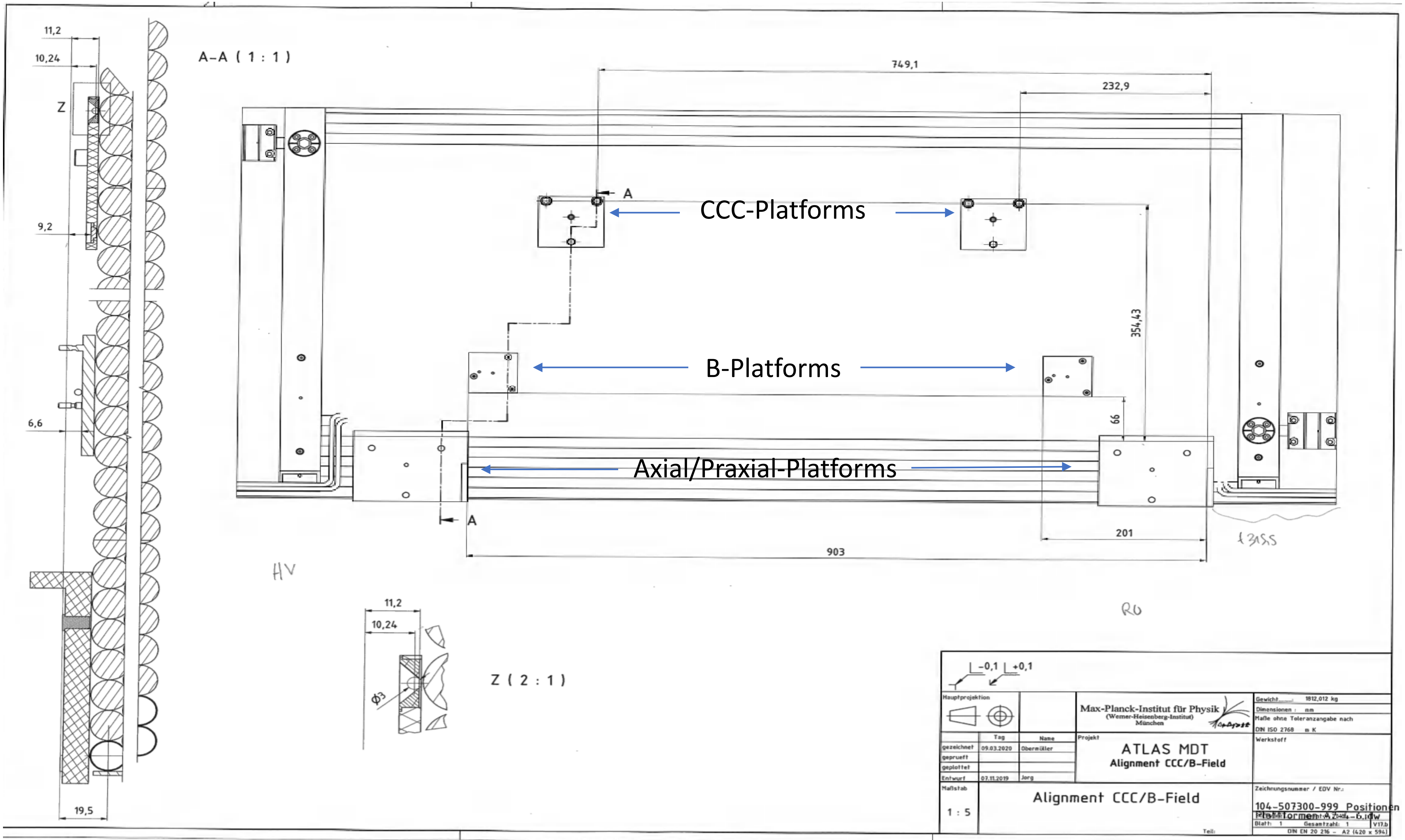


# Tests of BIS1 prototyp

- Platform measurements ( Axial- Praxial-Platforms, B-Platforms, CCC-Platforms)
- Torsion measurements
- Torsion measurements with different weights

➡ positioning of tubes important for precise momentum measurements

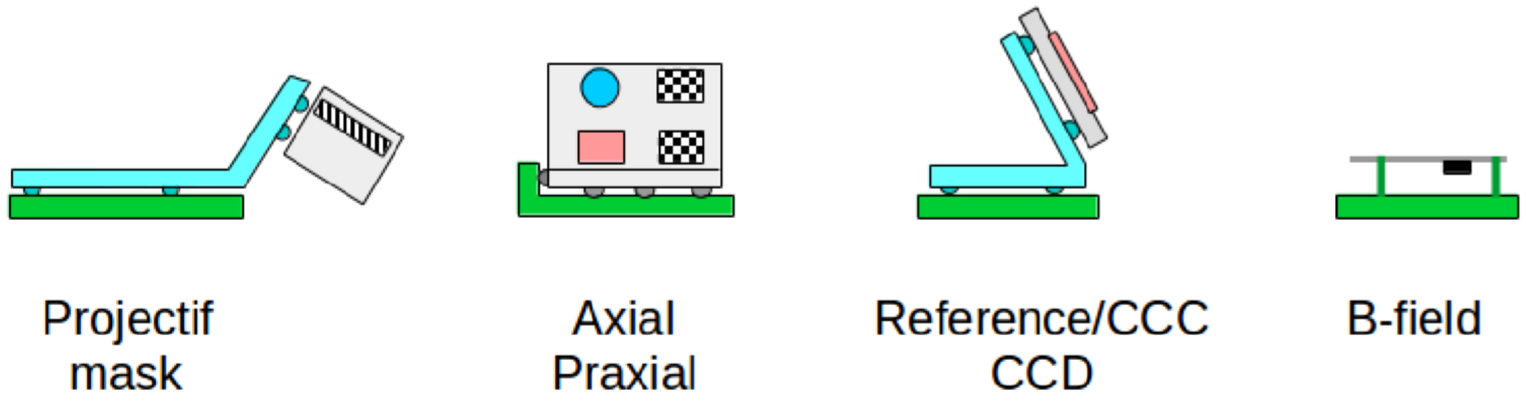
Goal: understanding the mechanical properties



A–A ( 1 : 1 )
Z ( 2 : 1 )
11,2
10,24
9,2
6,6
19,5
ϕ3
749,1
232,9
354,43
66
201
903
A
CCC-Platforms
B-Platforms
Axial/Praxial-Platforms
HV
RO
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)
München
ATLAS MDT
Alignment CCC/B-Field
Alignment CCC/B-Field
Hauptprojektion
gezeichnet 09.03.2020 Obermüller
Entwurf 07.11.2019 Jorg
Maßstab 1 : 5
Gewicht 1812,012 kg
Dimensionen : mm
DIN ISO 2768 m K
Zeichnungsnummer / EDV Nr.:
104-507300-999 Positionen Plattformen
DIN EN 20 216 – A2 (420 x 594)

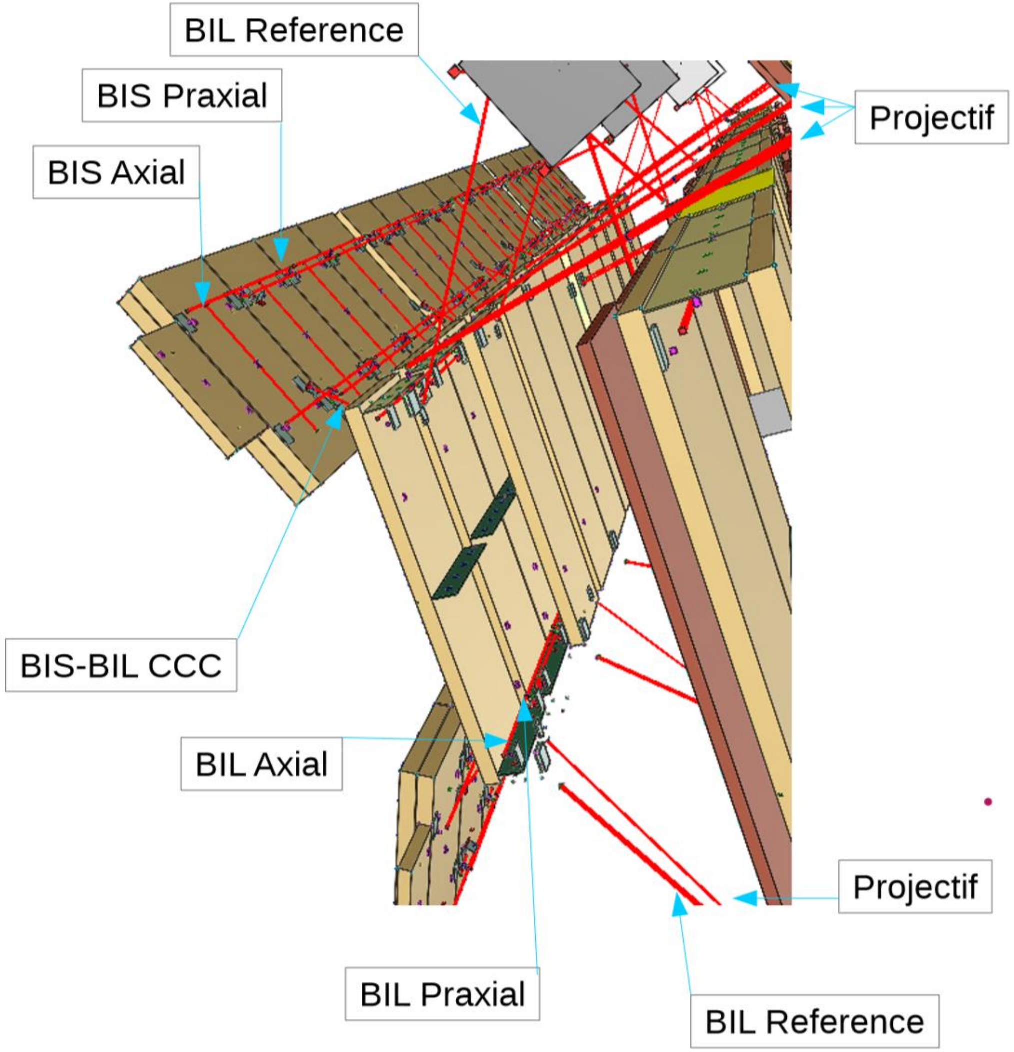
# Optical alignment system

1. Platform glued to chamber (green platforms)
2. Mechanical extension is attached to the platform (blue)
3. Optical elements are mounted on the extension (grey)



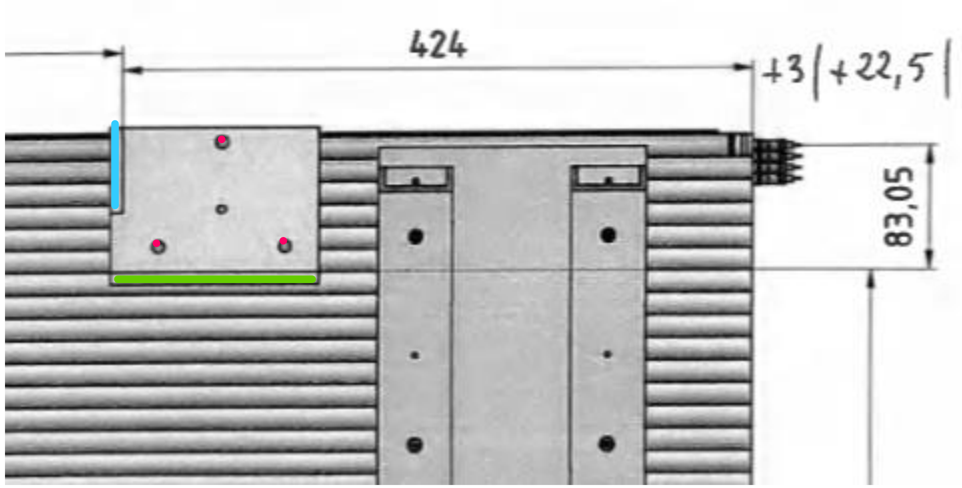
# Features of the Alignment system

- Monitors chamber positions in real time
- Only two out of three chambers have projectives/lenses
- Projective lines connect 3 chambers
- Reuse of existing alignment mechanics and sensors
- Positions of optical elements have to be measured precisly to reduce errors



# Test set-up for AP-Platform measurements

- Height above wire
- Distance to x-axis
- Distance to y-axis



| | side 1 | |
|---|---|---|
| | AP Platforms | |
| Distance between Platforms | 909,993 | |
| standard deviation | 0,007 | |
| deviation to reference value | -0,007 | |
| reference value | 910 | |
| | HV | RO |
| | | |
| height of platforms | 19,486 | 19,578 |
| standard deviation | 0,012 | 0,001 |
| deviation to reference value | -0,014 | 0,078 |
| reference value | 19,5 | 19,5 |
| distance of platforms to x | 91,696 | 91,653 |
| standard deviation | 0,0524 | 0,004 |
| deviation to reference value | 0,046 | 0,03 |
| reference value | 91,65 | 91,65 |
| distance of platforms to y | 1359,376 | 449,385 |
| standard deviation | 0,012 | 0,009 |
| deviation to reference value | 0,134 | 0,134 |
| reference value | 1359,5 | 449,5 |
| height of endcaps | 373,838 | 373,818 |
| standard deviation | 0,04 | 0,045 |
| deviation to reference value | 0,166 | 0,146 |
| reference value | 373,672 | 373,672 |

Results of side 1 for the Axial- and Praxial-Platforms

| | | |
|---|---|---|
| | side 2 | |
| | AP Platforms | |
| Distance between Platforms | 909,983 | |
| standard deviation | 0,002 | |
| deviation to reference value | -0,017 | |
| reference value | 910 | |
| | HV | RO |
| | | |
| height of platforms | 19,443 | 19,489 |
| standard deviation | 0,006 | 0,001 |
| deviation to reference value | -0,057 | -0,011 |
| reference value | 19,5 | 19,5 |
| distance of platforms to x | 83,048 | 82,998 |
| standard deviation | 0,008 | 0,003 |
| deviation to reference value | -0,002 | -0,052 |
| reference value | 83,05 | 83,05 |
| distance of platforms to y | 1225,388 | 315,401 |
| standard deviation | 0,003 | 0,005 |
| deviation to reference value | -0,112 | -0,1 |
| reference value | 1225,5 | 315,5 |
| height of endcaps | 373,83 | 373,878 |
| standard deviation | 0,014 | 0,013 |
| deviation to reference value | 0,158 | 0,206 |
| reference value | 373,672 | 373,672 |

Results of side 2 for the Axial- and Praxial Platforms

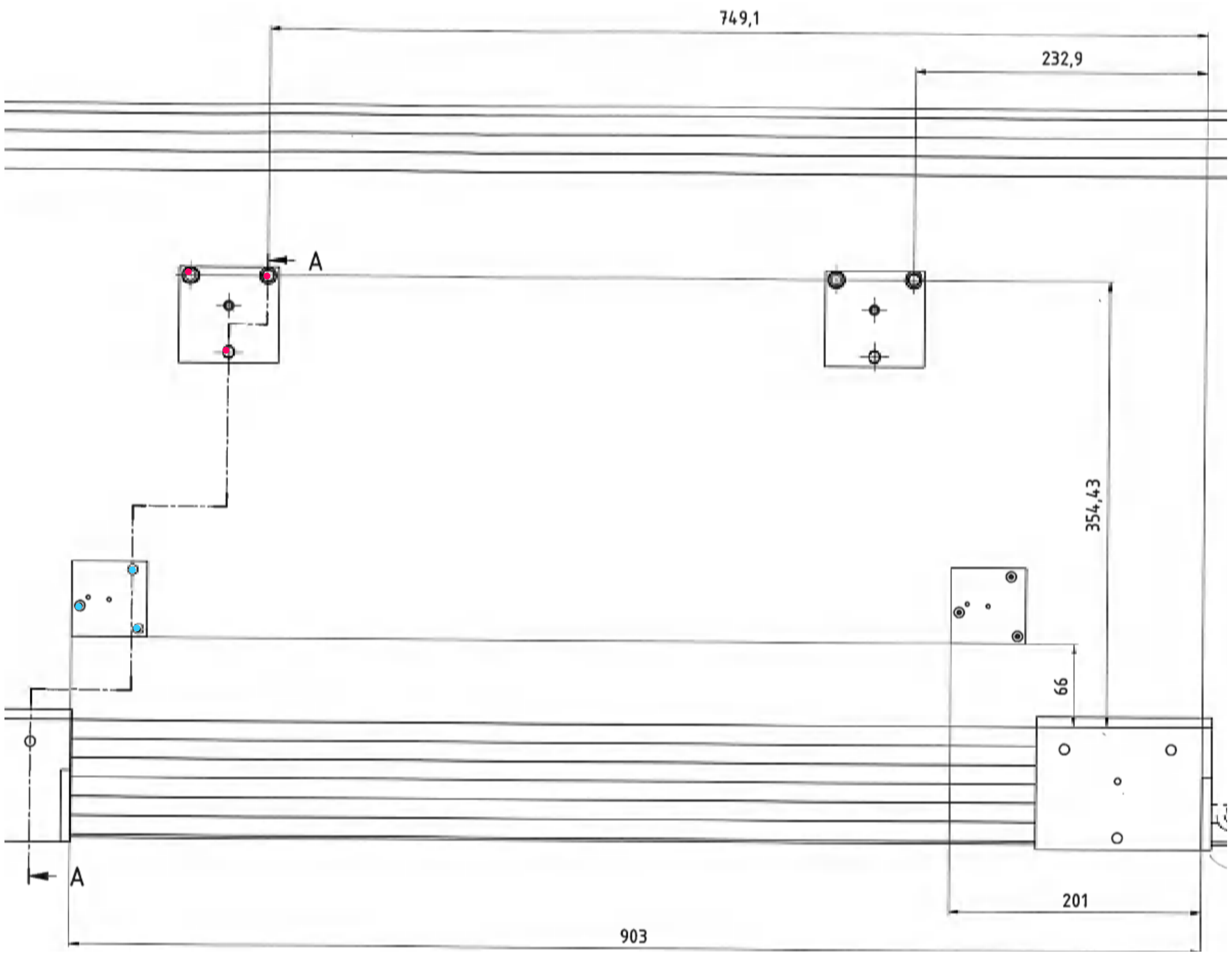
# Test set-up for B- and CCC-Platform measurements

B-Platforms:

X-Axis,  Y-Axis, height

CCC-Platforms:

X-axis, Y-axis, height

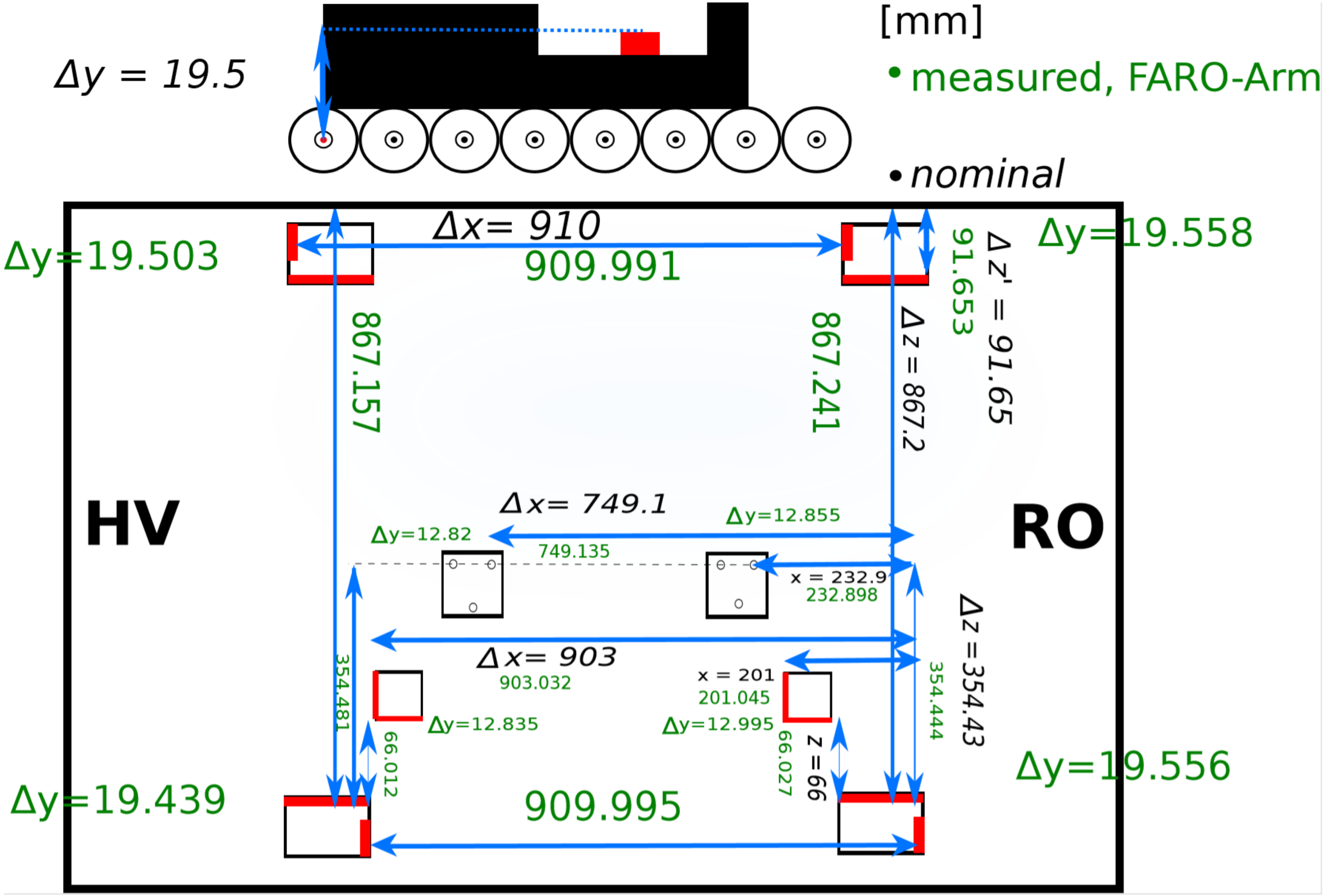


# Results of side 2 for the B- and CCC-Platforms

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | side 2 | | | | | | | |
| | AP Platforms | | B-Platformen | | CCC-Platforms | | | |
| Distance between Platforms | 909,983 | | 701,975 | | 516,213 | | | |
| standard deviation | 0,002 | | 0,003 | | 0,002 | | | |
| deviation to reference value | -0,017 | | 0,025 | | 0,013 | | | |
| reference value | 910 | | 702 | | 516,2 | | | |
| | HV | RO | HV | RO | HV | | RO | |
| | | | | | 1 | 2 | 1 | 2 |
| height of platforms | 19,443 | 19,489 | 12,849 | 12,948 | 7,732 | 10,346 | 7,614 | 10,319 |
| standard deviation | 0,006 | 0,001 | 0,028 | 0,015 | 0,001 | 0,013 | 0,024 | 0,011 |
| deviation to reference value | -0,057 | -0,011 | -0,051 | 0,048 | -0,568 | 0,046 | -0,686 | 0,019 |
| reference value | 19,5 | 19,5 | 12,9 | 12,9 | 8,3 | 10,3 | 8,3 | 10,3 |
| distance of platforms to x | 83,048 | 82,998 | 66,014 | 66,0356 | 354,393 | | 354,413 | |
| standard deviation | 0,008 | 0,003 | 0,007 | 0,003 | 0,008 | | 0,003 | |
| deviation to reference value | -0,002 | -0,052 | 0,014 | 0,036 | 0,093 | | 0,113 | |
| reference value | 83,05 | 83,05 | 66 | 66 | 354,43 | | 354,43 | |
| distance of platforms to y | 1225,388 | 315,401 | 903,023 | 201,048 | 749,067 | | 232,854 | |
| standard deviation | 0,003 | 0,005 | 0,009 | 0,007 | 0,005 | | 0,005 | |
| deviation to reference value | -0,112 | -0,1 | 0,023 | 0,048 | -0,033 | | -0,046 | |
| reference value | 1225,5 | 315,5 | 903 | 201 | 749,1 | | 232,9 | |
| height of endcaps | 373,83 | 373,878 | | | | | | |
| standard deviation | 0,014 | 0,013 | | | | | | |
| deviation to reference value | 0,158 | 0,206 | | | | | | |
| reference value | 373,672 | 373,672 | | | | | | |

# Results for all platforms

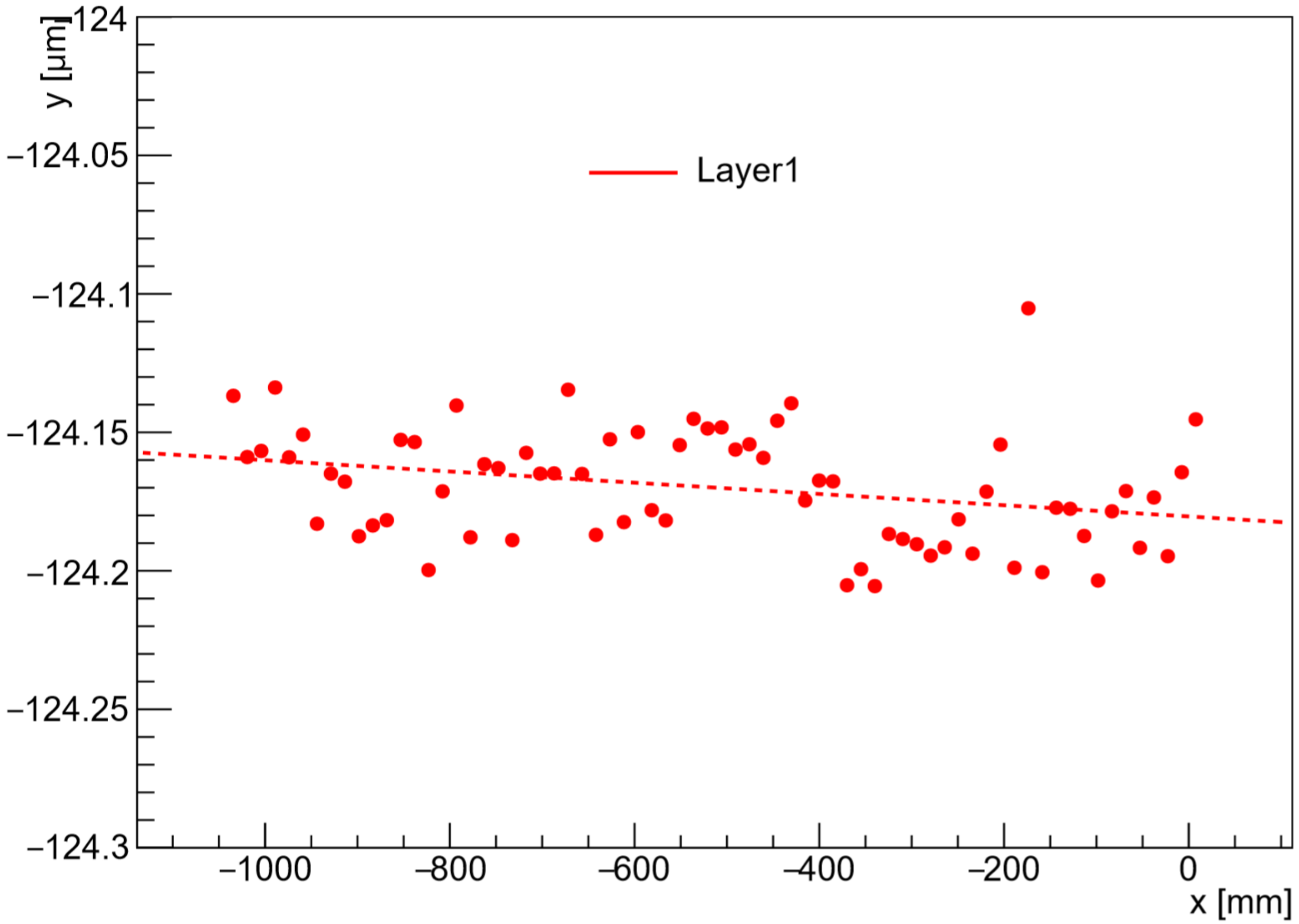
- Platform positions are precise enough
- Only small deviations to the reference values



# Torsion measurements

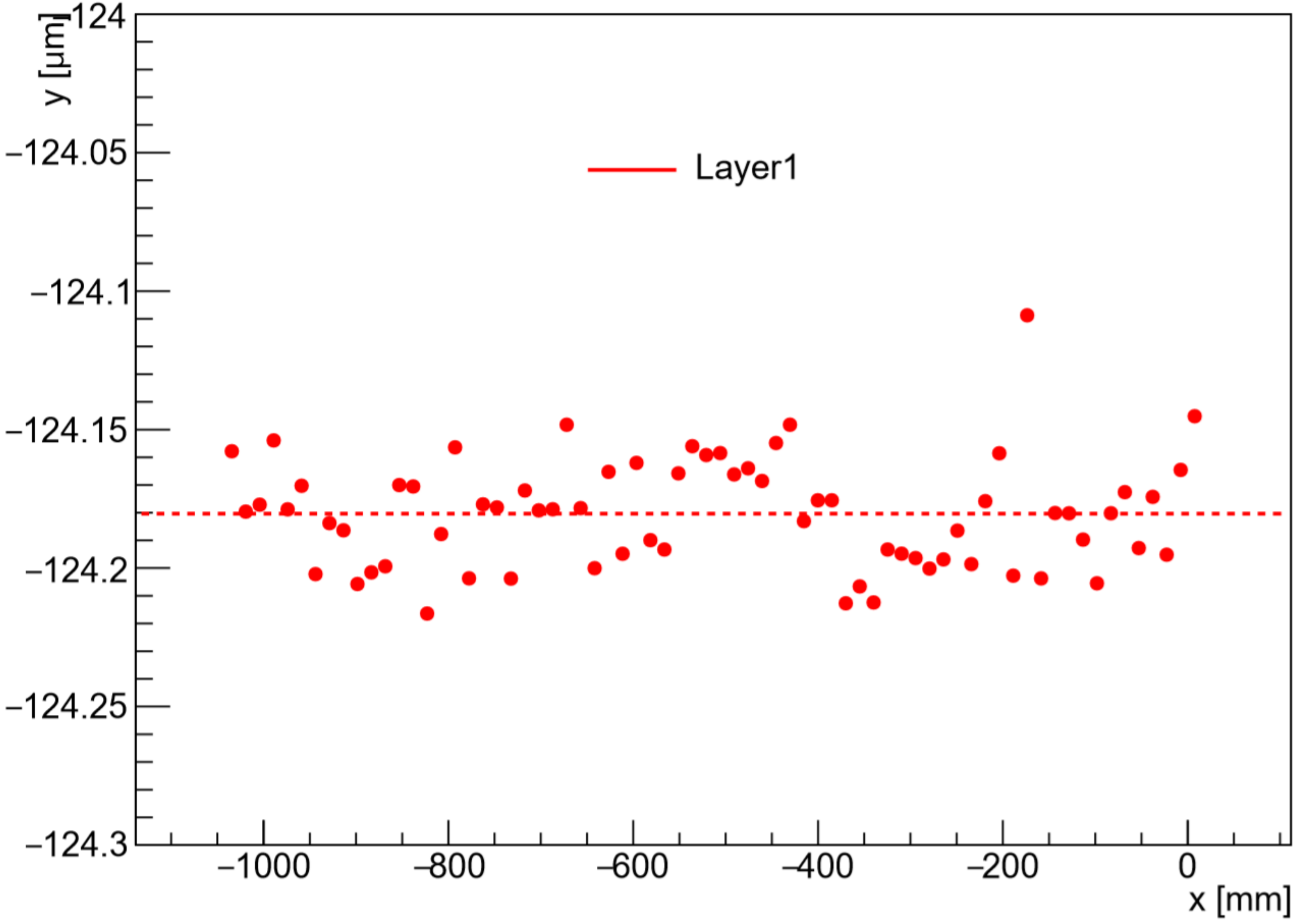
- After gluing of the chamber, the chamber is put out of the supporting structure
- Chambers now sag because of their own weight

# Sagging of one layer



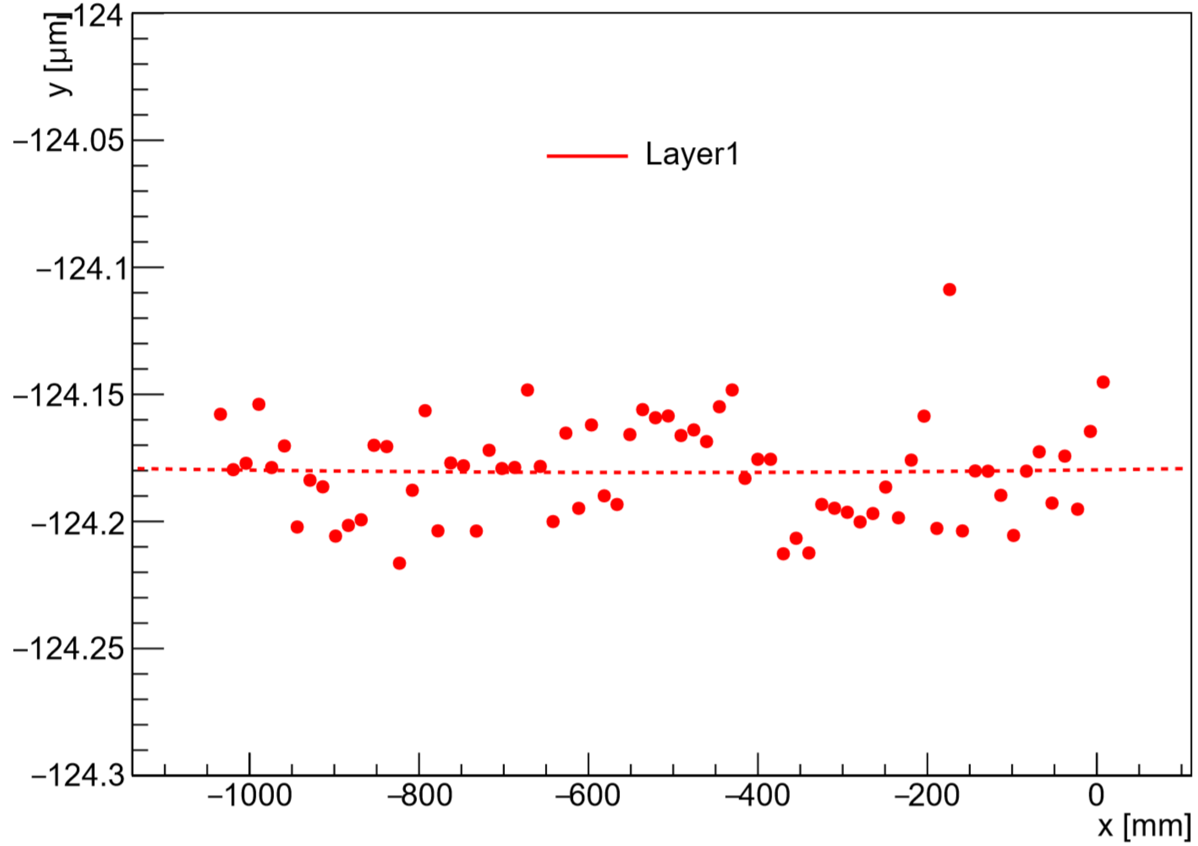

First step:

Linear fit of the measured points of each layer



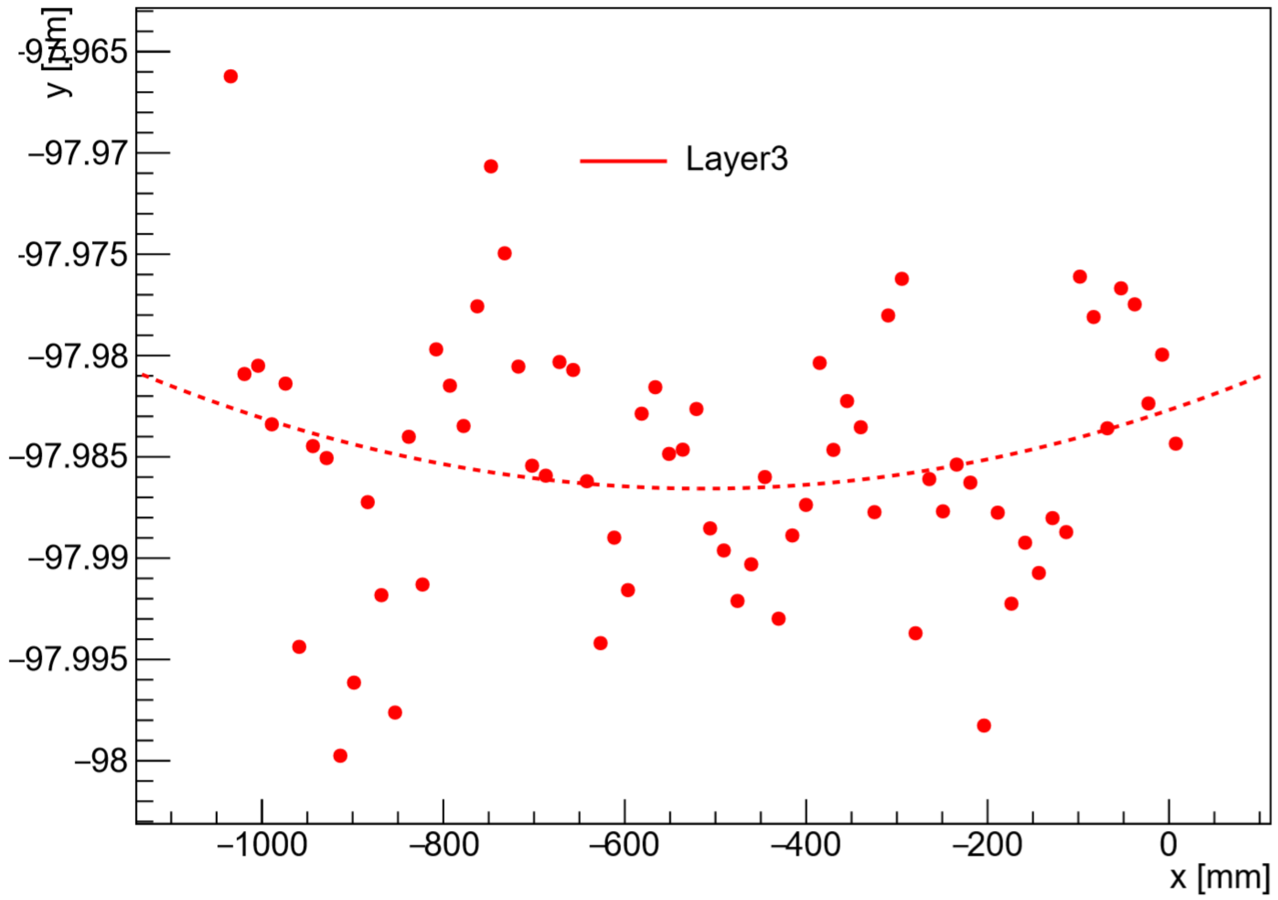

Second step:

Rotation of the coordinate system to get the x-axis parallel to the linear fit of the measured points of each layer

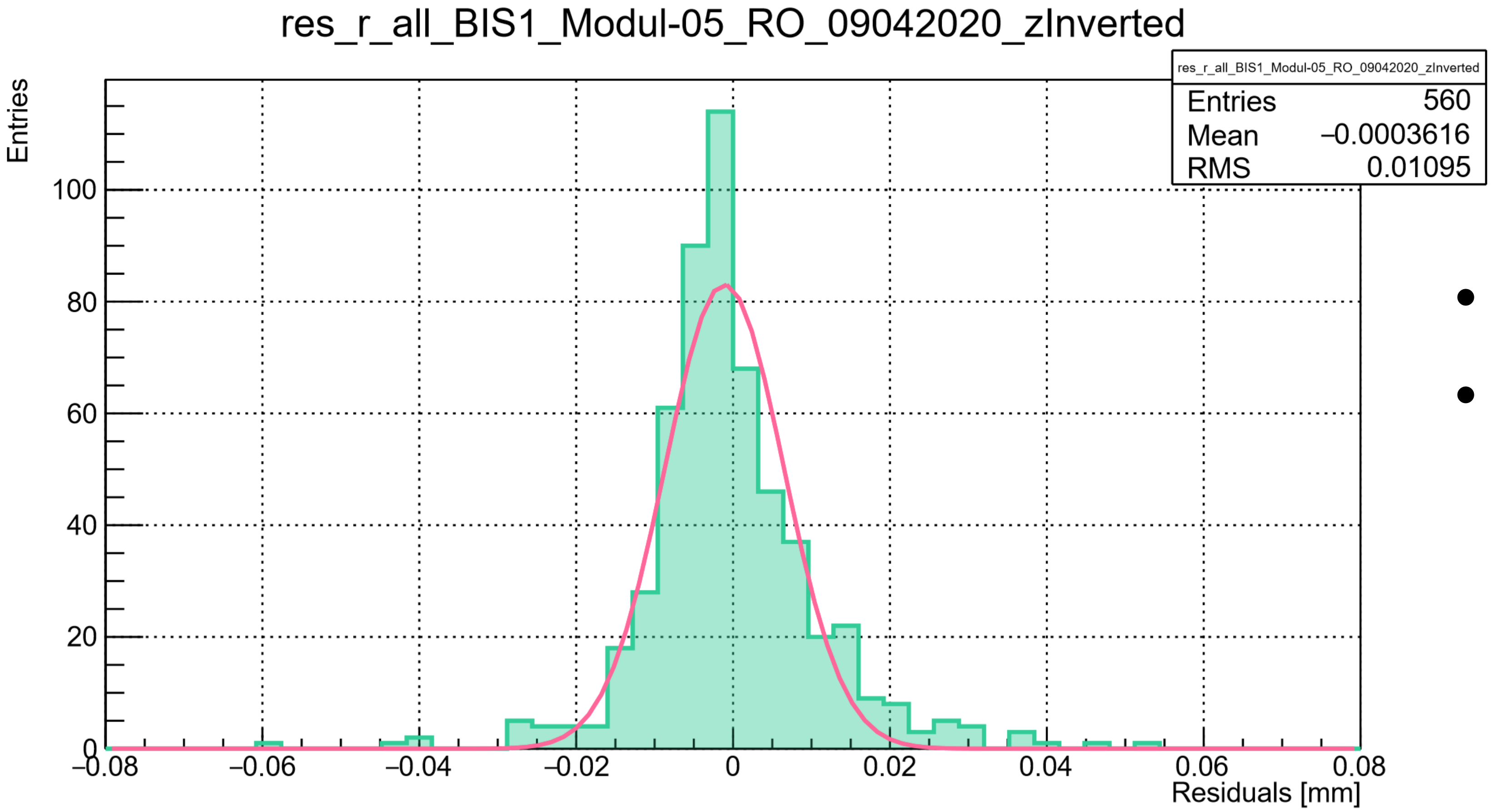



# Third step:

Fitting the points with a parabolic fit



# Deviation of endcaps from nominal value




- Normally distributed
- Standard deviation of 10μm

# Résumé

1. For the upgrade of the HL-LHC, additional RPCs will be installed in the inner barrel Layer of the muon spectrometer
2. MDTs will be replaced by smaller sMDTs
3. BIS78 chamber will be installed soon in the current shotdown
4. Currently preparing for the production of the BIS1-6 chambers
5. Mechanincal test of a BIS1 prototype chamber